COMPARISON OF AN ANALOG BEHAVIORAL AND TRANSISTOR LEVEL MODEL OF OPERATIONAL AMPLIFIER

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Summary In the present time of the electronics development lot of the measure equipments are standing in a very close neighborhood of each other.
The surrounding of them is then full of various signals of various frequencies and shapes. The electromagnetic influence of these equipments is important for their functionality and performance. The high frequency disturbance with the frequency of 1 MHz and more influence of course also the performance of the operational amplifiers. Lot of such circuits with the lower power consumption are also sensitive to the very small disturbances.
This paper is our contribution to the creating of an Analog Behavioral Model (ABM) of the OPAMP, which is one of the very powerful tool and can be used for the SPICE simulations. Some results of the simulations with our proposed model were compared with the measured results as well as with the SPICE simulations on the transistor level. The results showed the good agreement between the modeled and measured values.

1. CREATING AND DESCRIPTION OF AN ABM MODEL

We used for the preparation of our model as the reference the operating amplifier LF 355 and its simplified model parameters for the LEVEL1 – hybrid and transistor model of OPAMP in SPICE. The main features we need to cover in the proposed Analog Behavioral Model are: The temperature shift of the characteristics, the frequency dependence of the gain for open loop, CMRR of the input and output impedance, and offset caused by harmonic EM disturbance. The output voltage of the operational amplifier we can describe as the difference between (differential-mode Vindif) and (common-mode Vincm) of the input voltage as well as the positive (V+) and negative (V-) change of the power supply.

$$\Delta Vout = Adif.\Delta Vindif + CMRR.\Delta Vincm + (PSRR+).(\Delta V+) + (PSRR-).(\Delta V-)$$

According to this equation our macro-model will have four parts, each for an equivalent part of the equation above.

There are two possibilities for frequency characteristics modeling. One of the method is by using the equations with Laplace variable in the controlled sources. This method we can use by knowing the frequency dependence. Another way is using the piecewise linear Bode characteristic.

We preferred the first of proposed method, because of the time consumption during the simulation analysis.

The standard methods were used to determine frequency dependence of basic parameters. These values we used for “fitting” our macro-model. As a reference, datasheet of amplifier LF 355 was chosen.

The output voltage – gain is frequency and temperature depended. The CMRR (Common Mode Rejection Ratio) is modeled by “Laplace “ current source, which simulate the frequency dependence. The temperature depended resistor simulate the temperature dependence of the CMRR.

For the reaching of the high precise of the model we implement also the frequency dependence of the input and output impedance. We use the “ Laplace” ABM voltage source E1 with the current I(E1)=I(H1), measured by source H1 (Fig.1)

Using all simulated parameters from OPAMP LF 355 we create our behavioral macro-model.

Because of rather big schematic of ABM, we show it on the present poster only. There we explain and show which parts we included and simulate as the novelty of the model. The most important part is the block describing the EM disturbances.

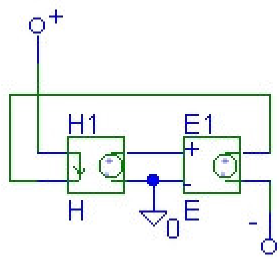

Fig. 1. The ”Laplace “ ABM voltage source

Our parametric model is available for any amplifier, for which we know its characteristics.

The whole schematics of the proposed model cover all important parameters. In the next part we will describe some examples of the simulation results of our ABM model compared with the results of the Level 1-hybrid and transistor level SPICE simulations.

2. SIMULATION AND COMPARISON OF TWO MODELS

The next Fig. 2 shows the Gain and dependence on the frequency for the proposed ABM model and the transistor level and Level 1-hybrid SPICE simulation. The comparison shows very small differences between both models.

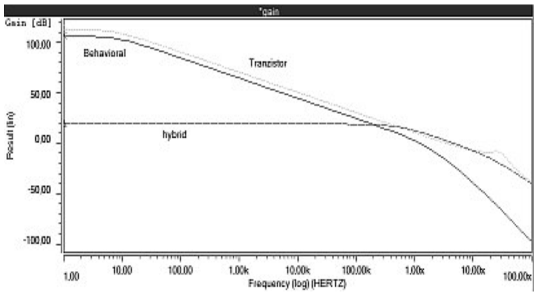

Fig. 2. The comparison of gain- frequency dependence for our proposed ABM model and SPICE Level 1 simulation

Other important characteristics of the OPAMP are simulated by both of the models and compared in the next Figures.

In the Fig. 3 we see the comparison of the transient characteristics and ability to simulate DC shift caused by EM disturbing. The possibility for simulating DC shift caused by EM disturbing is the main advantage in comparison with other models. Fig. 4 shows the output impedance comparison for ABM and the transistor Level 1-hybrid model available in SPICE and transistor level.

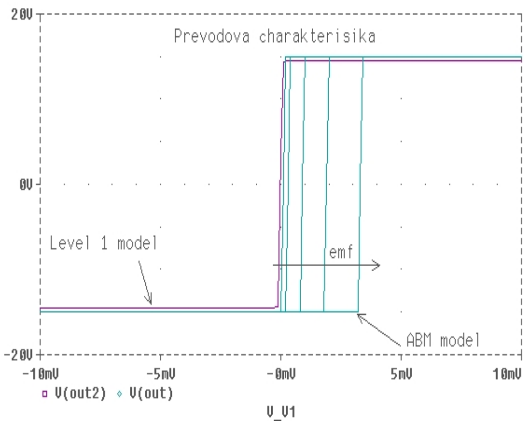

Fig. 3. The comparison of the transient characteristics for proposed ABM model and SPICE Level 1-hybrid simulations (emf - disturbing frequency)

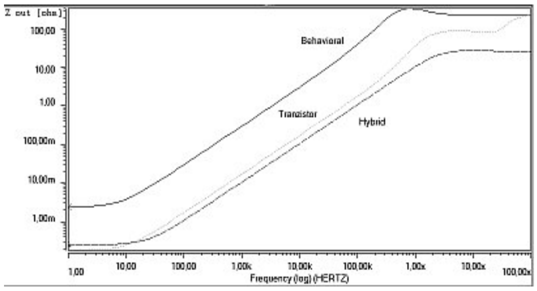

Fig. 4. The output impedance comparison for ABM model and Level 1 –hybrid and transistor level Model

From the comparison of both models (behavioral and transistor level) we see, that for the simulations of the EM disturbing effects is more valid the transistor level model, simulated by SPICE. The advantage is namely in the relatively good speed of the transient analysis .The behavioral model is more valid for the frequency analysis (AC).

From the simulation results we can also recognize, that the offset does not appear in the input stage of the Operational Amplifier, but it is created in its Stage 2 , Stage 3 and more. The offset is influenced by the compensation capacitor, which could also caused the its origin.

3. EXPERIMENTAL RESULTS

Measurements of the offset characteristics were performed on the module, which is typical for measurements of OPAMPs connected as non-inverting amplifier. Its gain was adjusted by changing the ratio of feedback resistors values. To filter the transfer of hf disturbance through feedback circuit small capacitor (1 nF) was placed between the non-inverting input of OPAMP and ground. Disturbing signal generated by signal generator was led through 6 dB attenuator to output circuit of measured OPAMP. For better impedance matching low value resistors (100 Ω) were added. This limited the amplitude swing of measured OPAMPs to 2 V. Signal from amplifier output was filtered by RC low pass filter, on which output the DC offset was measured by digital storage oscilloscope. Frequency for disturbing signal was swept within the range of 0.1 – 100 MHz. We made also some informative measurements with fast OPAMPs up to 500MHz. After the measurement the measured data were transferred from storage oscilloscope to PC computer. More about the measurement equipment is described in [1]

- The measured offset characteristics were practically identical for all OPAMPs of the same type. These results will be used for the future describing of our ABM macro model.

4. CONCLUSIONS

Performing the simulations, there is also important the velocity of simulations. The simulations of the simple circuits were realized on the PC with Intel Celeron 400 MHz processor. The results of the simple simulation analysis, which are covered by our ABM macro model are comparable for all typical simulations (.OP, .DC, .AC, .TRAN) with the simplified model (Level 1 –hybrid) .

The electronic devices (operational amplifiers included) are very sensitive to harmonic and pulse disturbances. These disturbances caused the offset, about which we have still in the present time not enough information and knowledge.

Therefore our effort is now concentrated to include the offset modeling (measured on the real OPAMPs) to cover also EM disturbances in the ABM model.

We showed in the presented paper the proposed ABM Analog Behavioral Model of the operational amplifier, which is simple configurable from the known characteristics. Using proposed ABM we can partly simulate also the influence of the harmonic disturbances.

As we showed in the previous part, this model is more precise as the simplified Level 1 model and is adaptable for the various types of the common OPAMPs. The disadvantage of this model is rather long time duration of the simulation analysis for the case of transient analysis.

This model we consider to spread in the very next future to model the noise, which together with the EM disturbances simulations will be the subject of our next investigation.

The electronic devices (operational amplifiers included) are sensitive to any harmonic and pulse disturbance. These disturbances caused the offset, about which in the present time is our knowledge still not enough clear. In the present paper we created the behavioral model of the operational amplifier, which is simple configuration from the known dependences and partly we can simulate influence of the harmonic disturbances. The proposed model is universal and usable for any operational amplifier. The disadvantage of the proposed model is the long time consumption during the simulations. This model is prepared for the next future to investigate also for the noise modeling as well as the EM disturbances simulations.

Acknowledgements

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REFERENCES

[1] HALLON, J., KOVAC, K., SMIESKO, V.: Sensitivity of Single Supply BJT OPAMP to Pulse Disturbance and its Modeling. International Scientific Conference Radioelektronika '02 : Bratislava 2003, pp. 390-394.

[2] CATRYSSE, J.: Measured Distortion of Output Waveform on an Integrated OPAMP Due to Substrate noise, IEEE Transaction on Electromagnetic Compatibility, Vol. 37, No 2, May 1995, pp. 310 – 313.

[3] TUINENGA, P.W.: SPICE- A Guide to Circuit Simulation and Analysis, Prentice Hall, New Jersey, 1988.